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VFC-FFC Hybrid Control For Full-bridge LCC Resonant Converters Based on Single-Carrier Modulation

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Abstract

The traditional variable-frequency control (VFC) and fixed-frequency control (FFC) of LCC resonant converters have problems such as wide switching frequency variation and narrow ZVS range. Therefore, this paper proposes a single-carrier hybrid control for a full-bridge LCC resonant converter. At the same time of varying frequency, the phase-shift angle for LCC resonant converters is adjusted so that the circuit can achieve soft-switching operation in a slight variation of switching frequency. The control method can reduce the reactive power of LCC resonant converters and improve the utilization of magnetic elements. Finally, the simulation results show that when the input voltage is 100V-200V, the output voltage is 48V, and the output power is 100W-500W, the hybrid control reduces the switching frequency range by 42.3% compared with VFC and has a border range of soft switching than FFC.

Introduction

LCC resonant converter is widely adopted in industrial applications due to its soft-switching and the utilization of transformer parasitic parameters. LCC resonant converters have better voltage regulation than the series resonant converter and higher efficiency than parallel resonant converter under light load. Widely adopted control methods of LCC resonant converter are VFC and FFC. However, wide working condition variation would bring in wide switching frequency variation with VFC, which reduces the utilization of magnetic components and expand the current stress of switches and reactive power. FFC is easy to lose soft-switching condition.

This paper proposes a single-carrier hybrid control strategy. According to the principle of dual-carrier control, the relationship between switching frequency and conduction angle is built, and the dual-carrier is simplified into a single carrier. Through reasonable parameters design, switching frequency and phase-shift angle are adjusted simultaneously when the operational condition changes. Thus, the soft-switching operation is realized in a small frequency variation. Finally, the effectiveness of the proposed control strategy is verified by simulation.

Principle for VFC-FFC

The principle of dual-carrier modulation is as shown in Fig.2. Considering that dual-carrier modulation is difficult to realize in simulations and experiments, dual-carrier is simplified into the single-carrier, as shown in Fig.3.

$$f_s = -\frac{k_2^2\delta}{2(k_1+k_2)V_t\pi} + \frac{k_2}{2V_t} \quad (1)$$

$$V_m = k\left(\frac{V_e}{k_1} + \frac{V_e}{k_2}\right) \quad (2)$$

$$V_{e1} = k\left(\frac{V_e}{k_1} + \frac{V_t}{k_2}\right) \quad (3)$$

$$\arctan\left[\left(\frac{1+\omega_s^2 C_t^2 R_e^2}{R_e}\right)\left(\omega_s L_r - \frac{1}{\omega_s C_s} - \frac{\omega_s C_t R_e^2}{1+\omega_s^2 C_t^2 R_e^2}\right)\right] + \arcsin\left(\frac{\pi V_o k_v}{4nV_{in}}\left|1+\frac{C_t}{C_s}-\frac{C_t}{C_s}\left(\frac{\omega_s}{\omega_{sr}}\right)^2 + jQ_e\left(\frac{\omega_s}{\omega_{sr}} - \frac{\omega_{sr}}{\omega_s}\right)\right|\right) = \frac{\pi}{2} \quad (4)$$

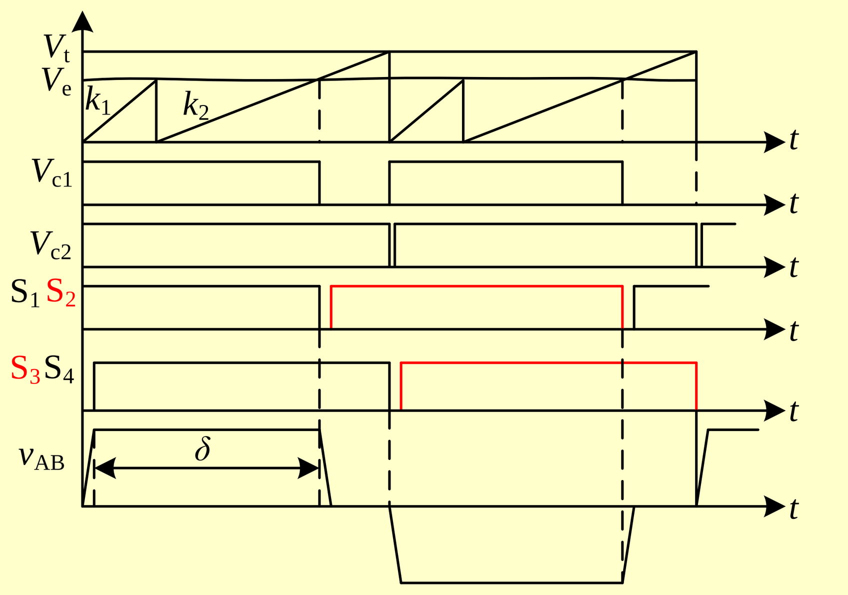


Fig.1.Dual-carrier modulation waveforms

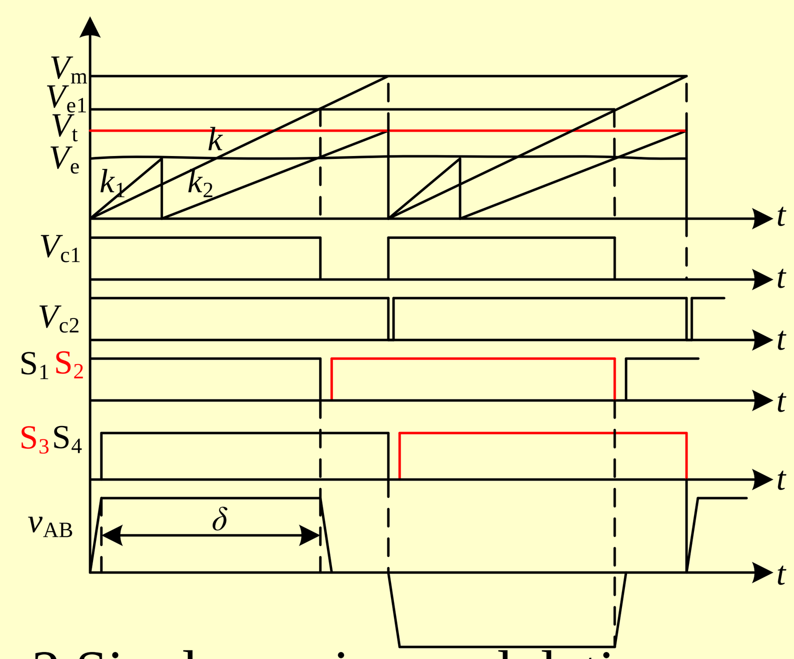
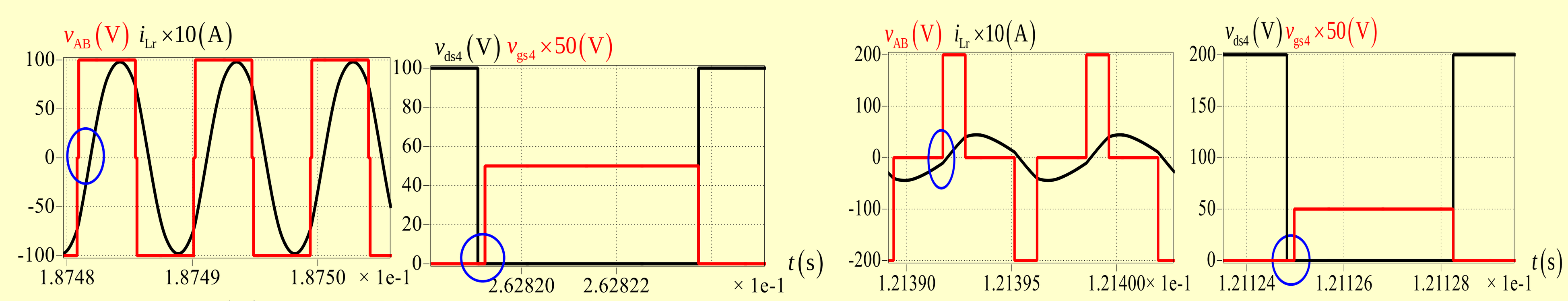


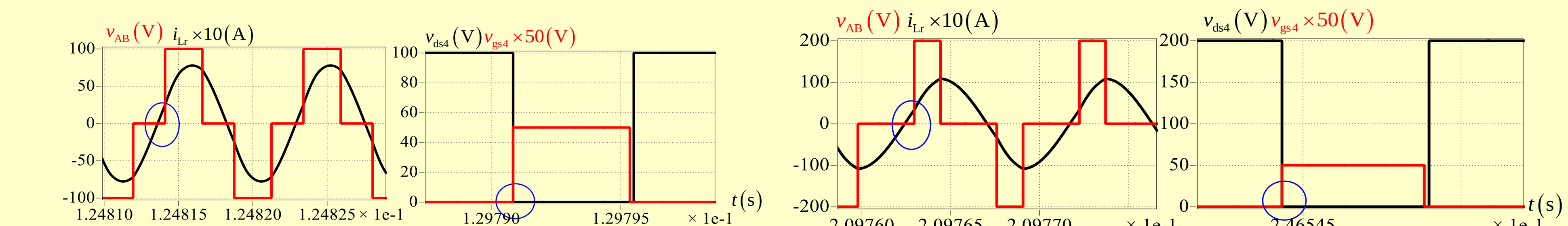
Fig.2.Single-carrier modulation waveforms

Simulation Results



(a)V_{in}=100V P_o=500W (b)V_{in}=200V P_o=100W

Fig.3.Simulation waveforms of hybrid control



(a)V_{in}=100V P_o=350W (b)V_{in}=200V P_o=500W

Fig.4.Simulation waveforms of FFC

Table I comparison of switching frequency range

Control strategy	f_{smin}	f_{smax}	Δf_s
VFC	107.4kHz	174.3kHz	66.9kHz
VFC-FFC	107.4kHz	146kHz	38.6kHz

Summary

To address the potential control challenges associated with LCC resonant converters, a single-carrier hybrid control technique for a full-bridge LCC resonant converter is proposed. The constraint relation between f_s and δ is established, and the dual-carrier system was simplified into the single-carrier system using the principle of constant conduction angle and switching frequency before and after the carriers change. In comparison to VFC, the proposed control approach exhibits a lower switching frequency fluctuation, resulting in less current stress on switches, less reactive power, and a wider ZVS range than FFC. Finally, the effectiveness of the proposed control method is verified by the simulation results.